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# TOPOCLIMATOLOGICAL SURVEY OF SWITZERLAND

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Mai 1982  
Final Report for HCMM-Investigation HCM-021

Prepared for  
GODDARD SPACE FLIGHT CENTER  
Greenbelt, Maryland 20771

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**PREFACE**

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When NASA 1975 offered the chance of participating in its Explorer-A mission program a group of Swiss scientists submitted an investigation under the title "Topoclimatological and Snowhydrological Survey of Switzerland" which was accepted by NASA. The main characteristic of the proposal was to apply satellite infrared data to subsynoptic climatic analysis, which is an extension to the main application of HCMM. An extended field and evaluation program was carried out by the Department of Geography of Berne University, whereas the snowhydrological part of the investigation had to be cancelled due to lack of manpower within the Department of Geography of Zurich University.

Analog and digital HCMM-data were provided either directly by NASA or through the French Space Meteorological Center in Lannion. For this generous support we have been very grateful. The bulk of the evaluation was carried out by Zdena SCHWAB and Gerrit NEJEDLY and further valuable contributions have been supplied by Dr. A. PIAGET. Their support is gratefully acknowledged.

The status of the investigation was reported to NASA in two progress reports and final results were presented at the investigators meeting, November 1980 at GSFC in Greenbelt.

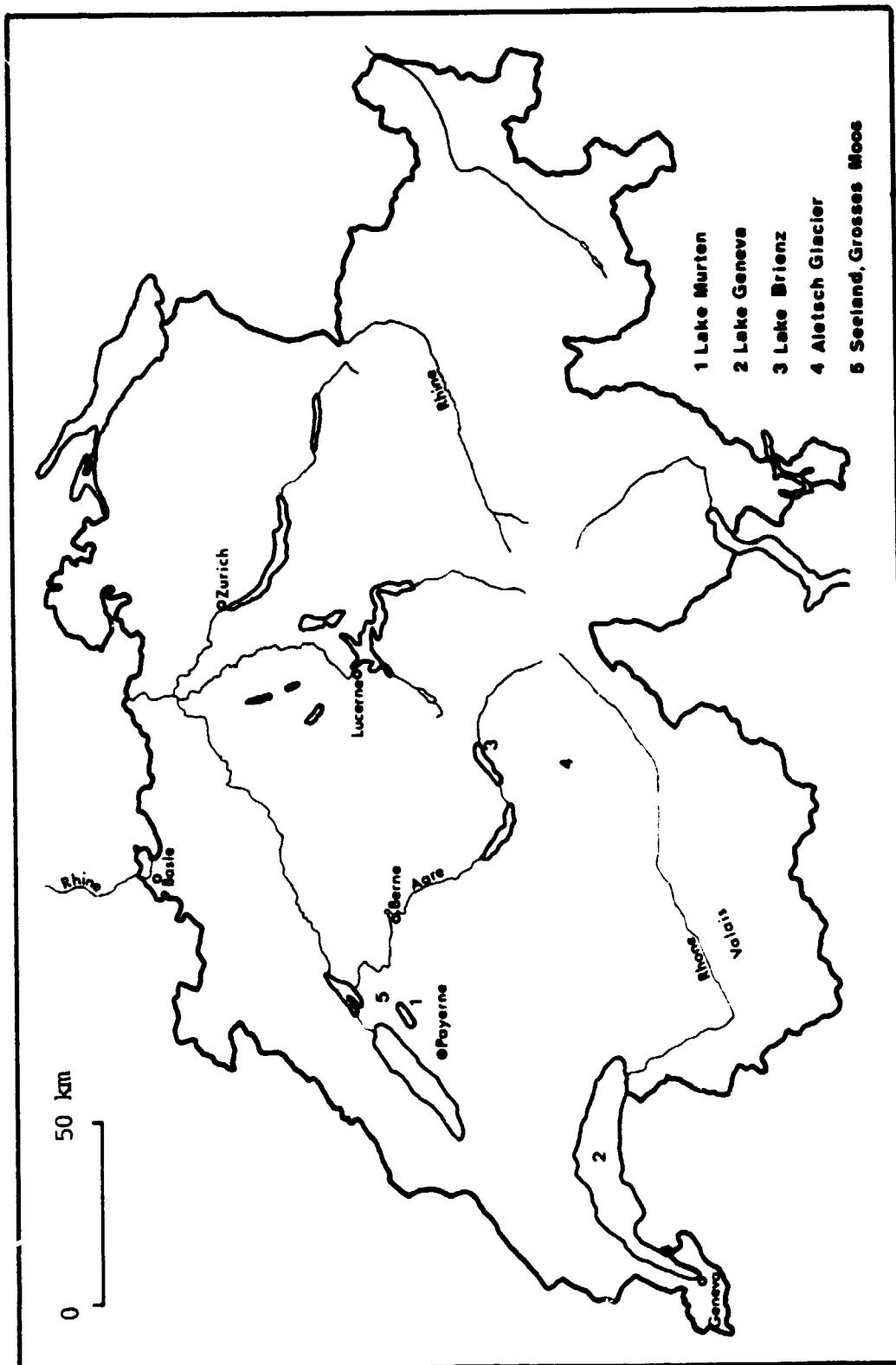
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Fig. 10 (Map of Switzerland with relative thermal patterns)  
is unbound added at the end of this report.

TEST AREAS OF HCMM - INVESTIGATION NO. HCM-021:  
TOPOCLIMATOLOGICAL SURVEY OF SWITZERLAND.

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## 1. THE USE OF SATELLITE DATA IN TOPOCLIMATOLOGY

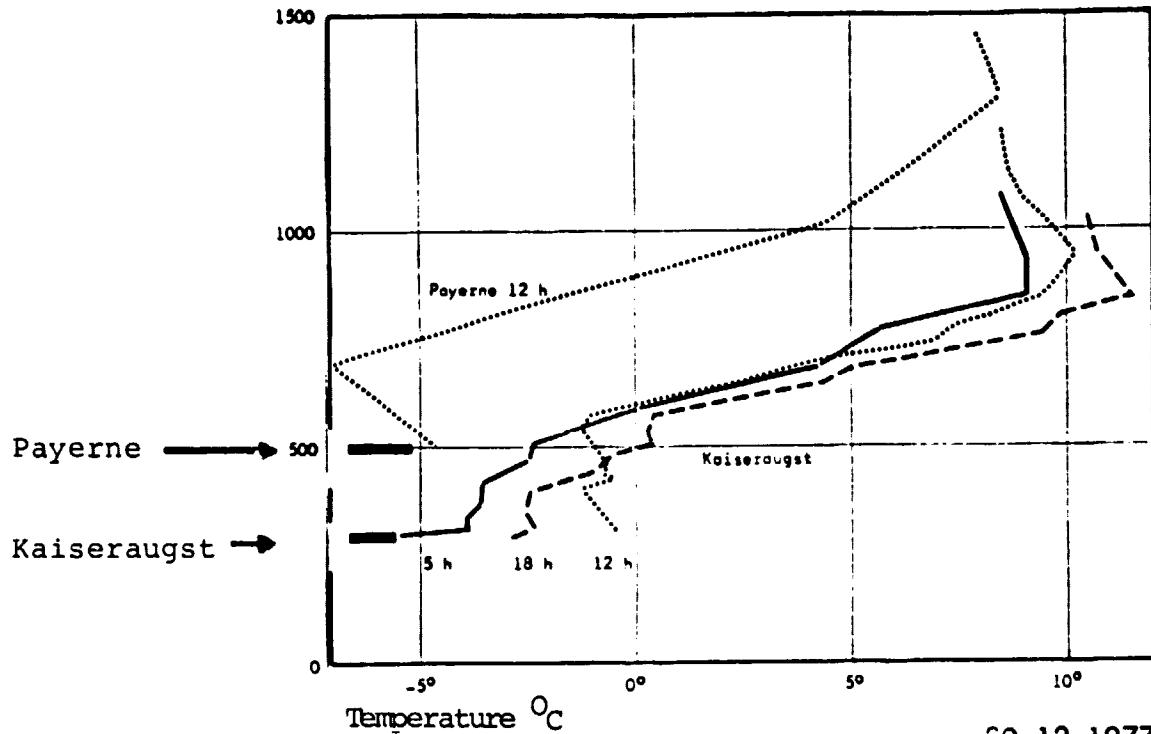
Within mountainous and hilly areas climatic situations vary significantly over very short distances. Above all, airflows are strongly influenced by the relief and within the valleys and basins, temperature inversions, mainly during the cold season or at night, reduce the vertical exchange of air masses. Inversion layers are frequently combined with haze or fog covers. As one of the consequences, agriculture and human settlements (housing, traffic) are exposed to an increased frost risk and to aggravated air pollution conditions.

Although, Switzerland has one of the most dense climatic networks a simultaneous evaluation of the inversion situation is very difficult to achieve, as most of the automatic climatic stations are located within the valleys and only one balloon sounding station exists (Payerne, Swiss Plateau). How significant differences of the vertical temperature distribution may occur within the boundary layer of two adjacent valleys is shown in fig. 1.

Instead of increasing the number of ground based observation points, a possible contribution of remote sensing techniques should be considered, all the more as infrared thermography has proven to be an useful tool in regional climatological investigations (urban heat islands). The use of respective satellite data would have the following advantages:

1. synoptic data collection with only one sensing instrument
2. operational (weather satellites) or semioperational (HCMM, LANDSAT-D) data collection
3. reduction of the amount of data compared to airbourne missions for regional investigations

Fig. 1: Air temperature conditions north and south of the Jura mountains: significant differences occur below 1300 msl as radio soundings (noon) of Kaiseraugst and Payerne show. General meteorological situation: high pressure over Central Europe, exceptionally well marked temperature inversion. Ref.: CLIMOD, 1981).



A significant limitation in mid-latitudes is cloud-coverage, which restricts the gathering of useful information to high-pressure weather situations. On the other hand, these meteorological situations are the most important for topoclimatological investigations.

The usefulness of HCMM-data for the following topics has therefore been studied:

1. Determination of the vertical extent of the temperature inversion zones
2. Determination of the horizontal airflow pattern.

To 1: The upper limit of a cold air mass can easily be detected, when it is marked by a fog layer. In other cases the question arises as to whether changes of the ground surface temperatures e. g. along a hill slope can be interpreted in terms of relative temperature changes within the neighbouring airmass.

To 2: Structures at the surface of fog layers or smoke plumes can be interpreted in terms of streamlines within the inversion layer

Preliminary studies for both questions showed that in many cases at least relative evaluations of the inversion situation are possible.

In fig. 2 the frequency distribution of the vertical limitation of inversion layers is mapped, using 200 NOAA- and HCMM images showing coverage above the Swiss Plateau.

Fig. 2: Vertical distribution of the upper limit of fog layers over the Swiss Plateau derived from weather satellite images. Cases with strong winds in the Upper Rhine Valley as a consequence of the overflow of cold air masses from the Swiss Plateau into the Rhine Valley are outlined separately (WINIGER: 1982: 221).

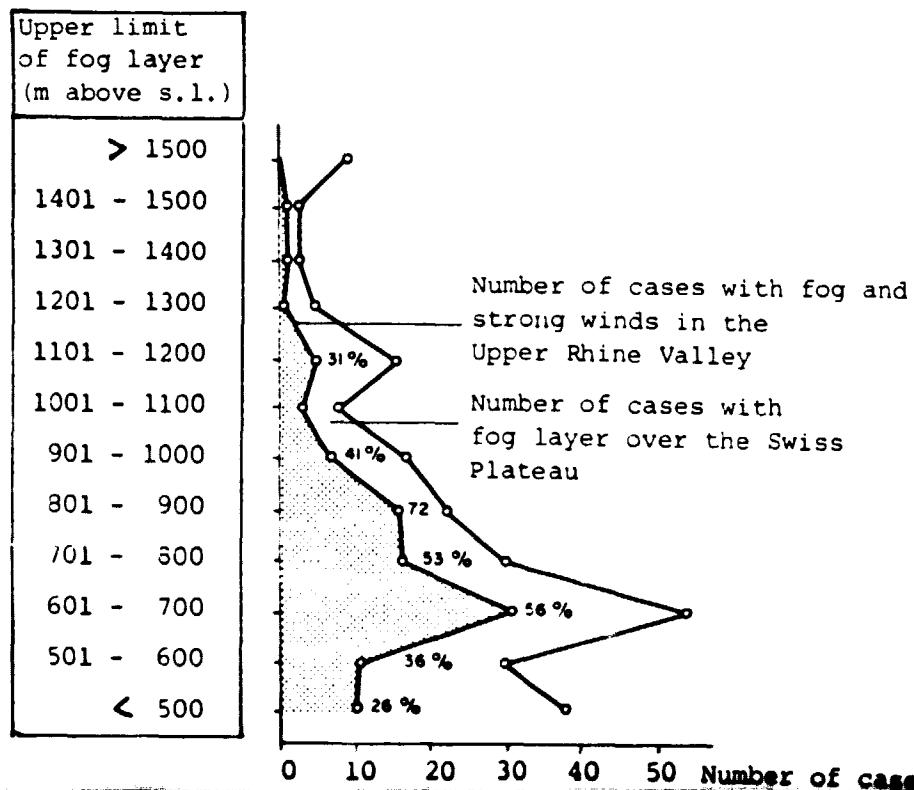
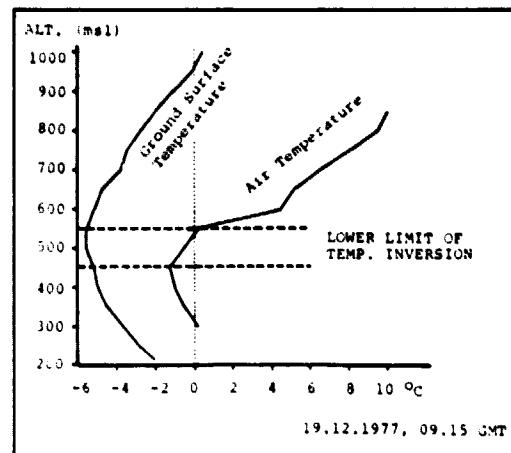


Fig. 3: Comparison between satellite derived ground surface temperatures and air temperatures (captive balloon) as a function of altitude (persistent inversion situation, region of Basel). Ref.: WINIGER in HAEFNER et al, 1980:72. See also fig. 1.



In fig. 3 a more sophisticated approach to the determination of the temperature inversion height is presented. Uncorrected radiation temperatures of a NOAA-5 scene (digital data from Lannion Satellite Receiving Station in France) are related to terrain altitude of the respective data pixels. A comparison of the resulting vertical surface temperature profile to a simultaneous balloon sounding show remarkable coincidence in the relative course of both curves. The result might have been improved if atmospheric data corrections as well as terrain coverage type had been taken into consideration. Finally, in fig. 4 the streamline pattern within an overflowing cold air mass is mapped using LANDSAT-data.

Compared to NOAA- and LANDSAT-data HCMM offers decisive advantages:

1. The spatial resolution of a pixel is appropriate to most topoclimatological questions of a regional scale, whereas NOAA-data (1 x 1 km<sup>2</sup>) are just at the critical limit for investigations within mountainous areas (the width of valley floors usually in the range of 1 km).
2. The local time of satellite passes is optimal for studies of inversions as well as urban heat islands. Only with TIROS-N and NOAA-7 comparable data collection times are now available.

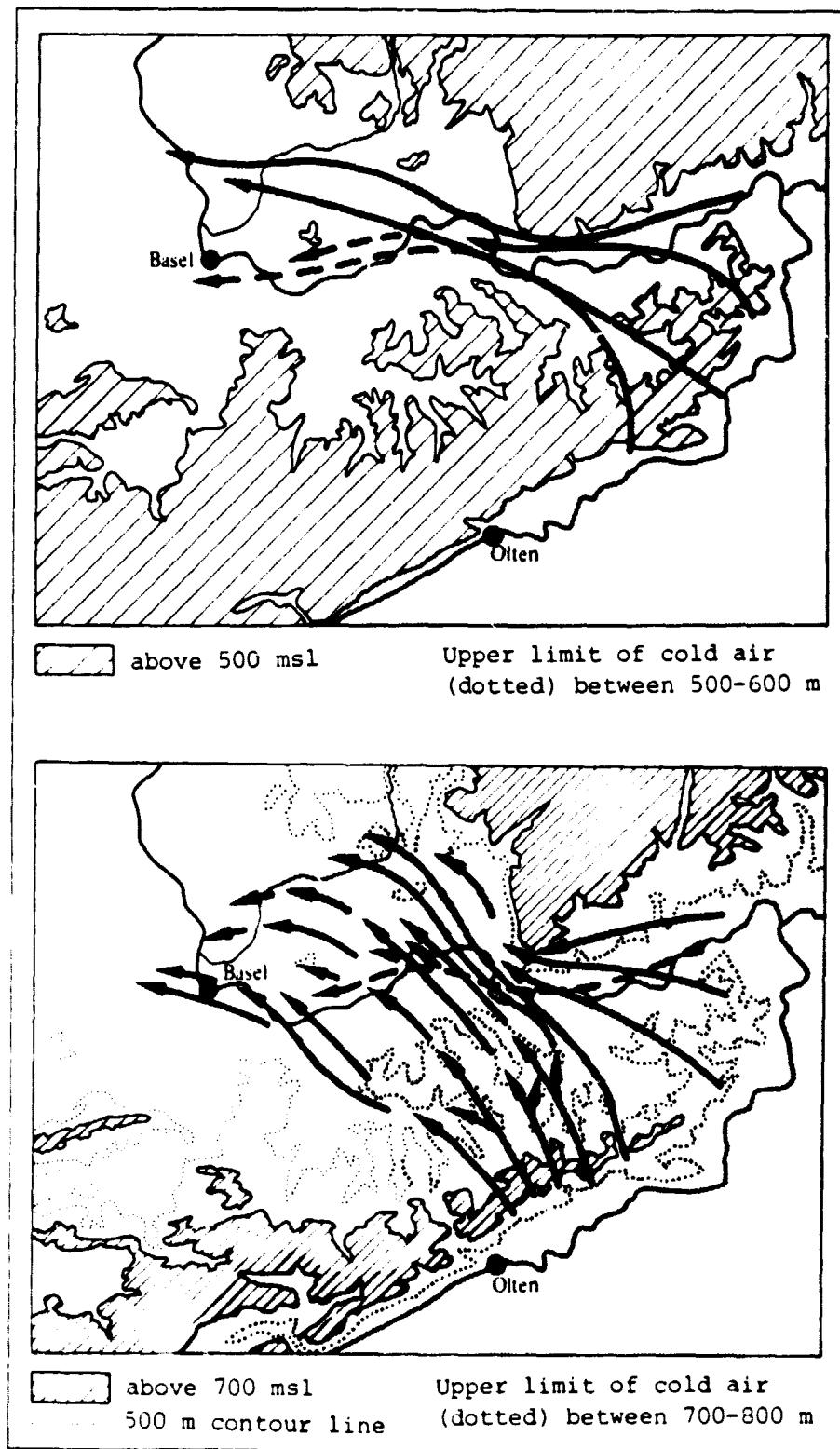


Fig. 4: Air flow pattern (streamlines) derived from satellite pictures. Cold air masses flow from the Swiss Plateau into the Upper Rhine Valley. Ref.: WINIGER, 1982:226.

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3. Compared to LANDSAT the frequency of satellite orbits over a specific area is significantly increased. This is important due to the fact, that at mid-latitudes cloud-coverage allows, only in about 10 % of the cases, an extensive evaluation of the terrain.

Related to the climatic interpretation of satellite data a concept as follows is considered as suitable (fig. 5):

Fig. 5: Concept for the use of satellite data for topoclimatology.  
Clouds, cloud structures and surface temperature as input data.

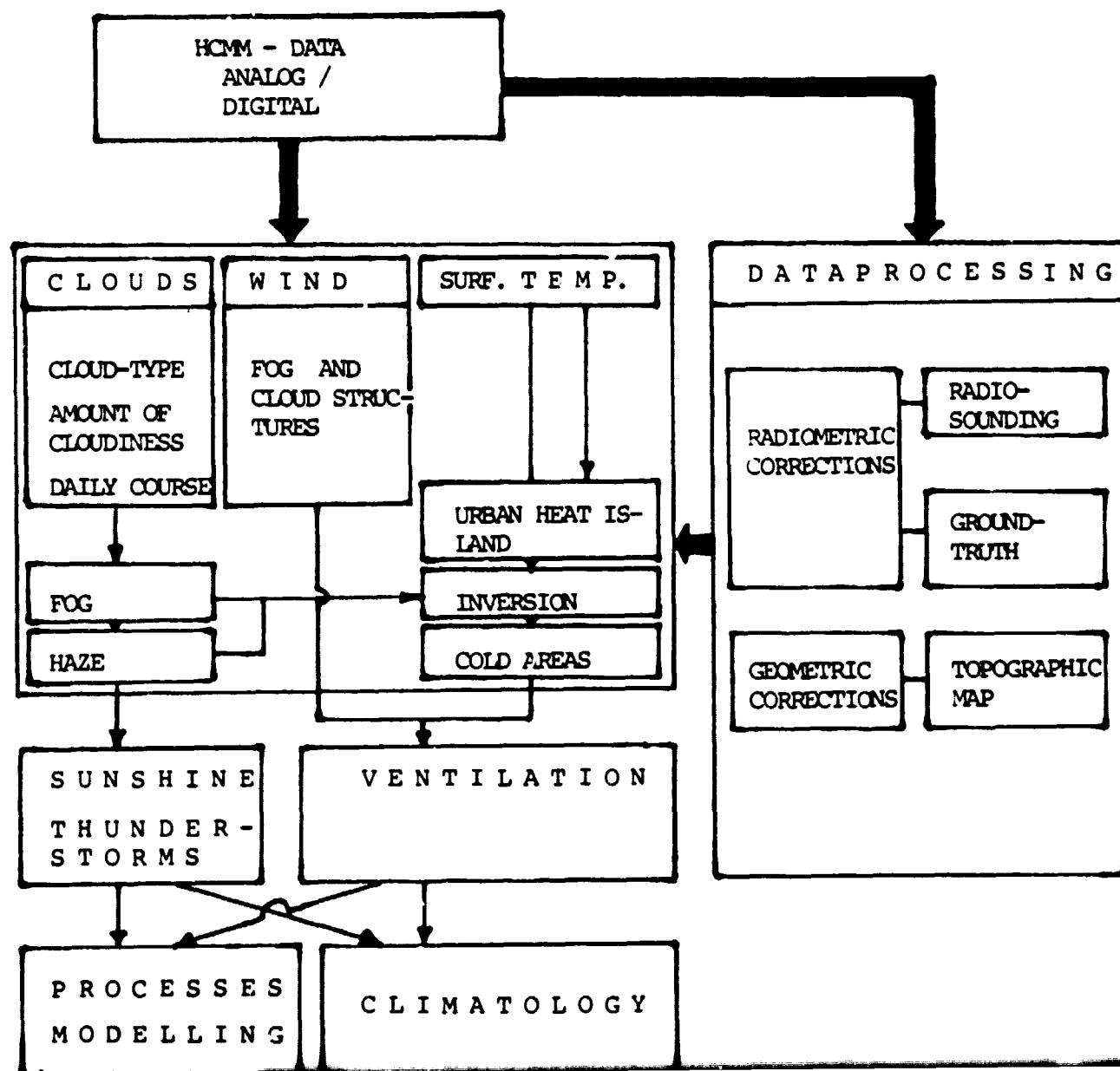
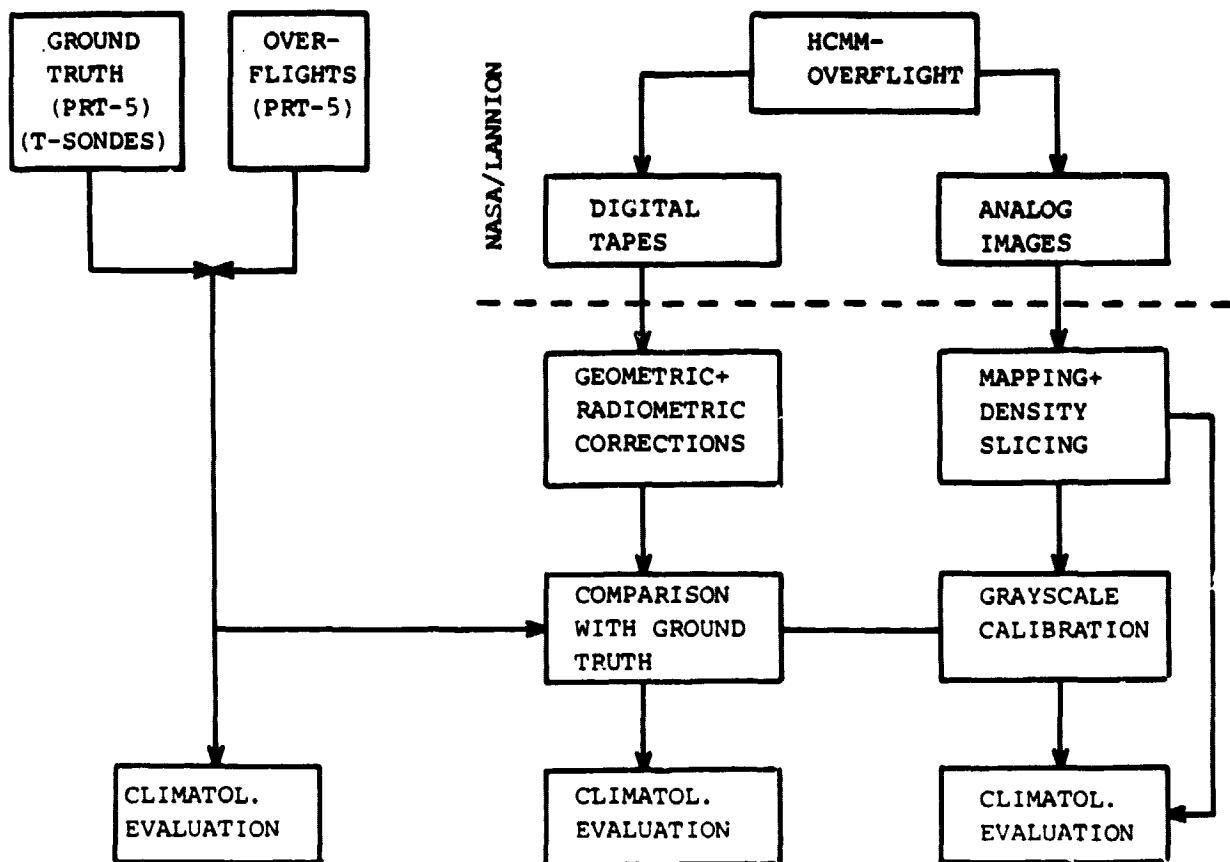


Fig. 6: Concept of the HCMM - investigation for a topoclimatological survey of Switzerland



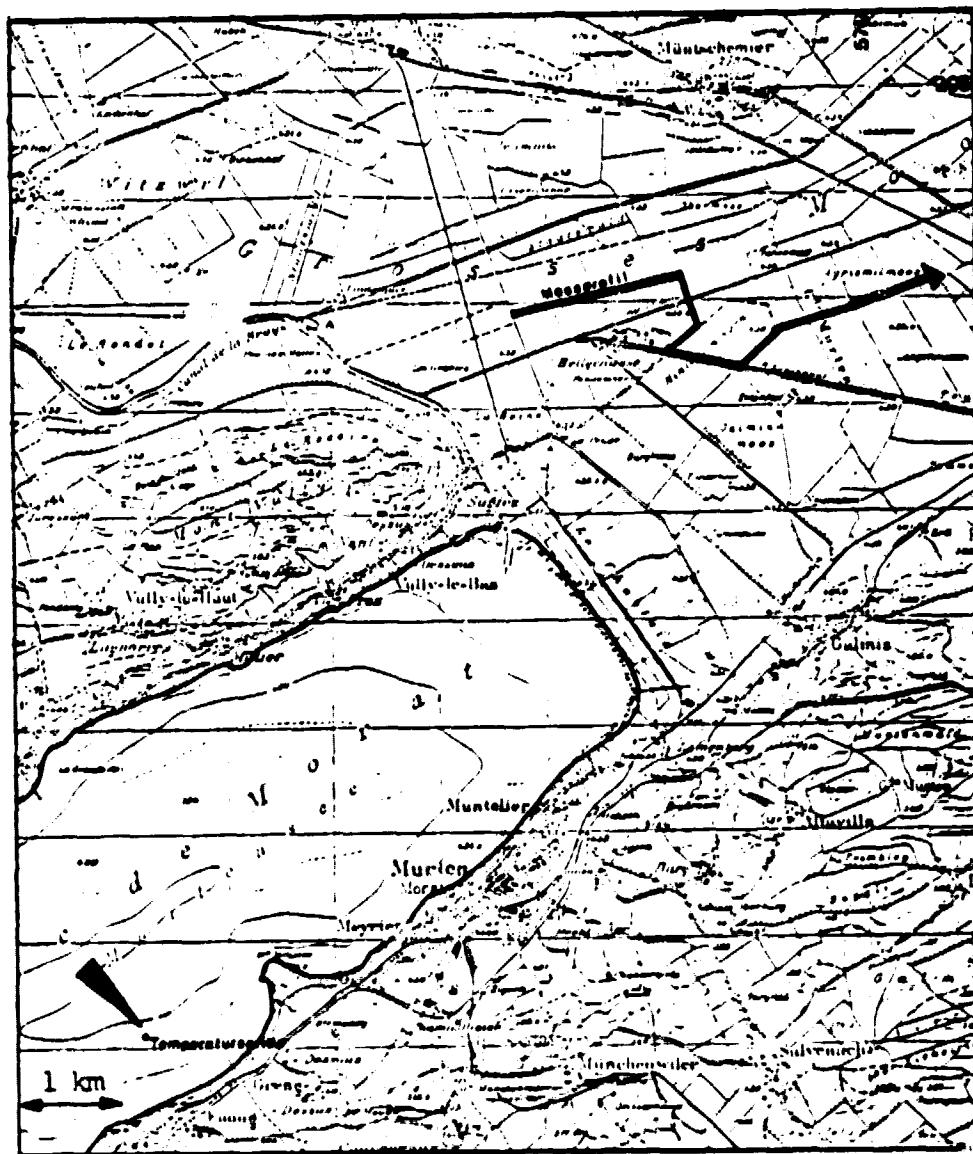
## 2. CONCEPT OF THE TOPOCLIMATOLOGICAL EVALUATION OF HCMM-DATA

The more general concept shown in fig. 5 had to be adapted for the HCMM-program (fig. 6). For our purposes not only digital CCT had to be evaluated but also analog uncorrected images (as they have been provided by NASA) were used, because some problems (fog mapping, delineation of cold valley floors) can be solved even more quickly and almost as accurately as with digital techniques. Emphasis was given to the comparison of satellite and ground truth data. Therefore, an extensive program of data collection with ground based sensors (lake surface temperatures), as well as with airborne radiation temperature measurements using the Barnes PRT-5 radiometer should provide enough simultaneous observations with the same type of sensors.

### 2.1. Data evaluated

During the working period of HCMM (1978 - 1980) some 300 scenes have been taken over Switzerland, from which we also obtained analog data. Of these imageries 23 could be used for fog cover mapping, 38 for the mapping of inversion layers and for studies on urban heat islands. Finally, 10 scenes have been evaluated in detail. For 10 overflights we got digital tapes, three of which have been put to further use.

Fig. 7: Ground truth data collection sites: Surface temperature of Lake Murten (►•) and 3 km profile covering different landuse types (crops) (—→). Ref.: NEJEDLY, 1980:71.



### 3. GROUND TRUTH PROGRAM

The collection of ground truth data should enable us:

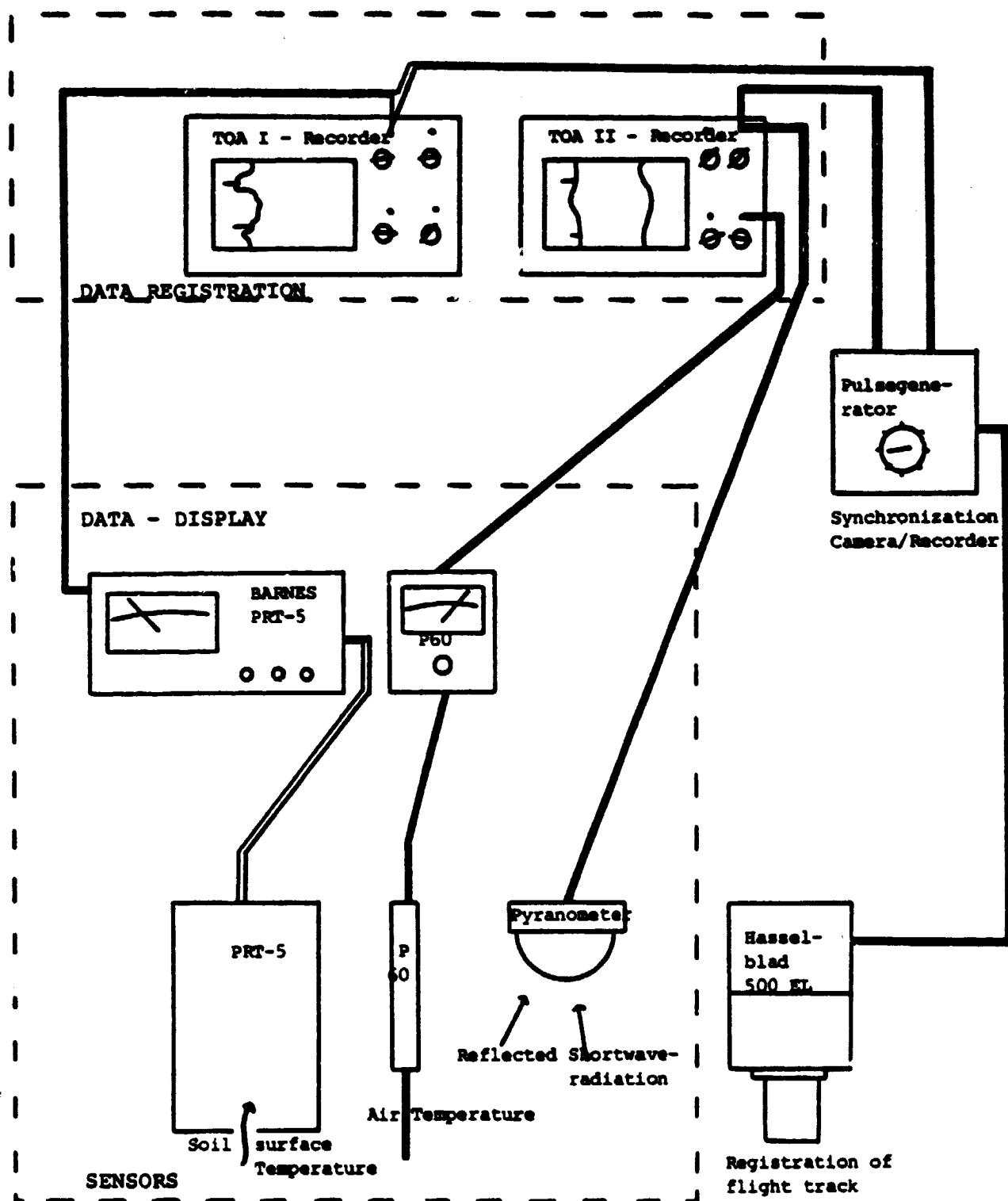
1. to estimate the accuracy of the satellite system
2. to get information about the interpretability of the radiometric data in terms of inversion climatology
3. to evaluate how the information contributing to one pixel has to be weighted

To achieve these goals different approaches have been chosen:

1. A thermistor (covered by a block of styropor) measuring the water temperature 1 cm below the lake surface (should collect continuous control data for a homogeneous surface (Lake Murten, 15 km west of Berne, fig. 7)).
2. In daytime, during summer, the temperature of melting snow is exactly 0 ° C. A uniform snow field at approximately 3000 m above s. l. was found on the Aletsch Glacier in the center of the Swiss Alps. For this altitude atmospheric corrections are usually not anymore necessary because on clear days the bulk of atmospheric humidity is concentrated within the boundary layer.
3. Simultaneous low altitude under flights with an instrumented aircraft as shown in fig. 8 served to collect radiometric data over land surfaces of different coverage types (forests, agricultural land, built up areas, lakes). Because of the typical small scale farming type of Switzerland and the distinct topography, this investigation was necessary in order to understand how satellite measurements are generated.

For ground truth measurements at night (02 UT) flight permission was not available. Therefore, an additional ground-based measuring program for mixed agricultural areas was carried out in the plain of "Grosses Moos", northeast of Lake Murten. Along a profile of 6 km length some 645 points were

Fig. 8: Instrumentation for airborne "ground truth" data collection



sampled over 10 different crop types. The surface temperature was measured with a Barnes radiometer PRT-5. Temperature shifts during the sampling time of 70 minutes were corrected and reduced to the moment when the satellite passed over. Considering the different agricultural crops in the area of the "Grosses Moos" and using representative temperature values for each crop type the "true surface temperature" of 29 km<sup>2</sup> was calculated. Consecutive comparison with the respective 100 pixels of the HCMM scene (including the necessary atmospheric correction) a mean difference between satellite and ground based measurements was determined (see p. 19).

#### 4. ANALOG DATA EVALUATION

As already mentioned, some of the non-quantitative evaluations (fog mapping, wind patterns, relative temperature distribution, structure of urban heat island) were based directly on the provided transparencies (either positive or negative IR or VIS images). Fog and wind analyses were carried out by simple photo interpretation methods, such as delineating the interesting features visually and transferring them to topographic maps by using the Bausch & Lomb Zoom Transfer-scope (ZTS). More complex temperature structures as e. g. cold areas on valley floors or urban heat islands were first outlined by using opto-electronic devices, mainly the Bausch & Lomb Omnicron Alpha, which provide density slicing capabilities, including measurements of specific areas and form parameters. Most important was shading correction to minimize interpretation errors.

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Fig. 9.1.: Surface temperature pattern in an Alpine Valley (Wallis): the valley floor is appr. 500 m asl, the mountain tops reach between 3000 - 4000 m. The thermal pattern is typical for all Alpine valleys: cold valley floors, warm slopes and cold tops.

Analog interpretation derived from HCMM-scene Nov. 16, 1978, 01.36 UT

(Portion of separate map added as Fig. 10)



Fig. 9.2.: Surface temperature pattern in the Basel area. The valley floor is covered by a fog and haze layer. A clear thermal inversion is marked some 600 m above valley floor.

Analog interpretation derived from HCMM-scene Nov. 16, 1978, 01.36 UT

(Portion of separate map added as Fig. 10)



COLD (MOUNTAIN TOPS)



COLD (VALLEY BOTTOMS)



WARM (VALLEY SLOPES AND TOPS)



HAZE, FOG

SCALE:



Although, no quantitative results (related to thermal data) can be achieved, analog methods proved to be very efficient. Beside the simple and fast evaluation procedures the interpreter is very flexible in decision-making. For instance, for delineation of either fog boundaries or cold zones, no strict radiation criteria exist. In the case of fog or dust (especially on night IR-scenes) the absence of any topographic information (such as rivers, hills, forests etc.) is more significant for the decision "fog" - "no-fog" than a specific thermal value. Or in the case of cold valley zones as well as warm hill slopes, delineation on a local scale is usually very relative because different basins and valley floors are located at different altitudes and consequently show different absolute temperature values.

As an example of both, fog mapping and outlining cold valley floors, fig. 9 (relative temperature pattern of Switzerland) is shown. The map is based on a nighttime IR scene of November 16, 1978. The temperature pattern derived is very typical, at least for the valley floors, which on most night scenes during the cold season are almost identical. This means that local effects, such as topography and ground coverage type (forest, grassland, agricultural land, urban) together with local air temperature inversions are predominant factors. Only air temperature inversions some hundred meters above ground can be related to changes in the surface temperature, which then differ from case to case, depending on the depth of the inversion layer. In fig. 9 such an inversion can be outlined in the hills around Basle (upper edge of the map), some 600 m above the valley floor. Although NASA, as well as the Lannion facilities, clearly pointed out that analog

transparencies are of only limited value for absolute temperature measurements, we tried to get some indications about the size of error that might occur using pictures instead of digital information.

Using digital data for gray scale calibration we compared areal extents of the same temperature intervals ( $\Delta T = 3.0 ^\circ C$ ). Differences ranging from 10 - 25 % resulted from this comparison which could be reduced significantly for greater intervals but would increase for smaller ones.

## 5. DIGITAL DATA EVALUATION

Determination of a surface temperature model ( $T = f$  (topography, surface coverage type, soil conditions etc.) or multitemporal approaches (thermal inertia), are possible with pixelwise digital data analysis. Equally, temperature calibration procedures, including atmospheric corrections, have to be based on digital data.

In our approach we followed the different steps outlined in fig. 11.

To achieve the different steps listed in fig. 11, we made a set of computer programs (written in FORTRAN, see figs. 12, 13).

In the following sections geometric and atmospheric corrections are briefly described.

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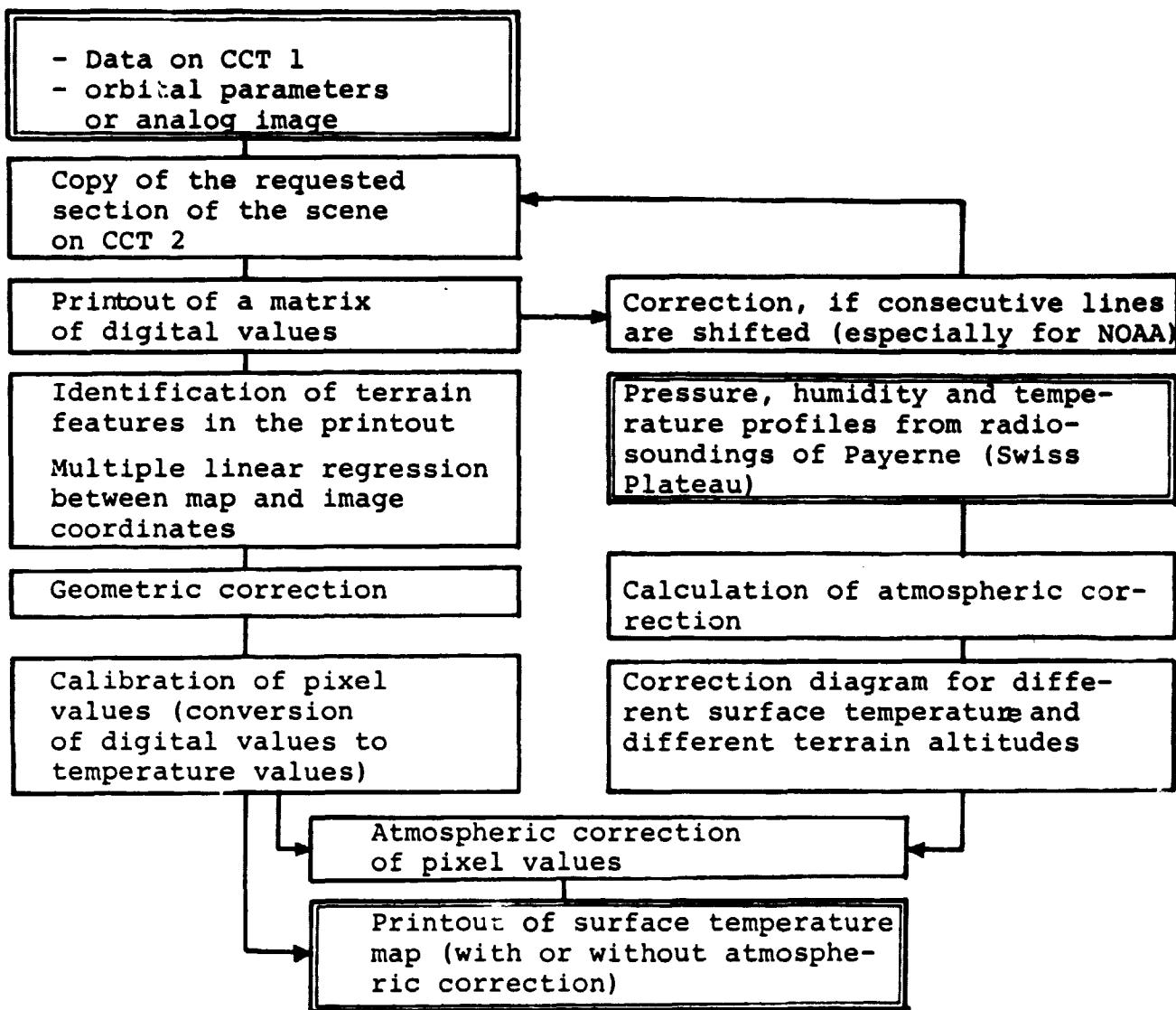
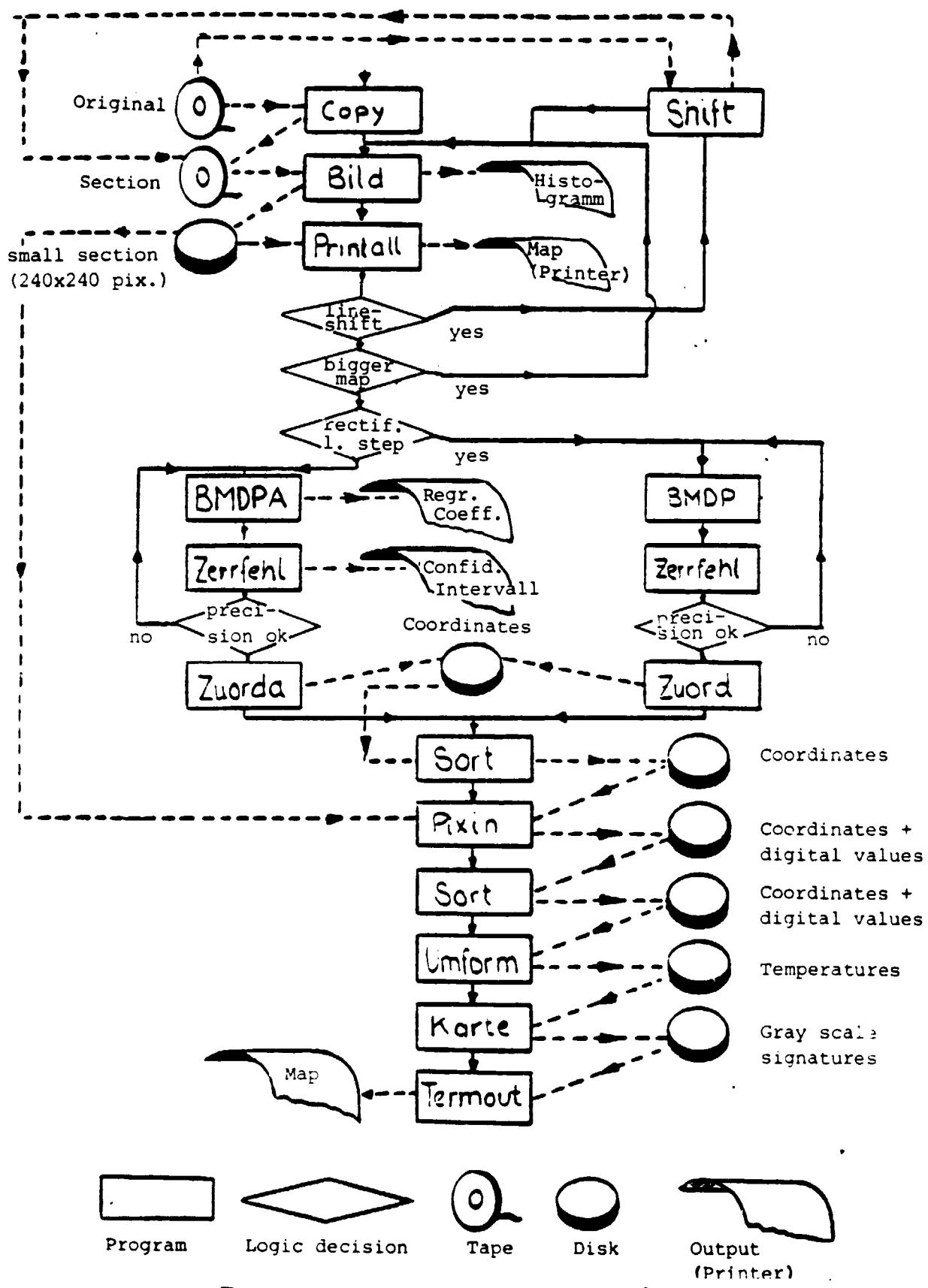


Fig. 11: Evaluation scheme of HCMM (and NOAA) data  
(SCHWAB, 1981 : 55)

### 5.1. Geometric corrections

The preprocessed HCMM-data which have been adapted to a HOTINE OBLIQUE MERCATOR projection by NASA had to be further adapted to Swiss topographic maps on the scale of 1 : 200 000 with an oblique cylinder projection (inc. congruity). To get a reasonable correlation between Swiss map coordinates (1 km -

Fig. 12: Computer programs, operating sequence and data flow for the evaluation of HCMM data (SCHWAB, 1981:56)



grid) and HCMM image coordinates, an accuracy of appr. 1 km in locating the image pixels was required. Using maps and LANDSAT-images, distinct terrain features were located within the HCMM scene. Some 30 - 50 points, distributed around the area to be rectified, were used to determine statistically (multiple linear regression) the linear transformation between the two projections.

Stepwise improvement of the correction results was possible by calculating image coordinates of the selected points, using the determined regression coefficients. Points with deviations of more than 3 pixels were eliminated. Final location accuracy of  $\pm 1 - 2$  pixels within a 95 % confidence interval was achieved.

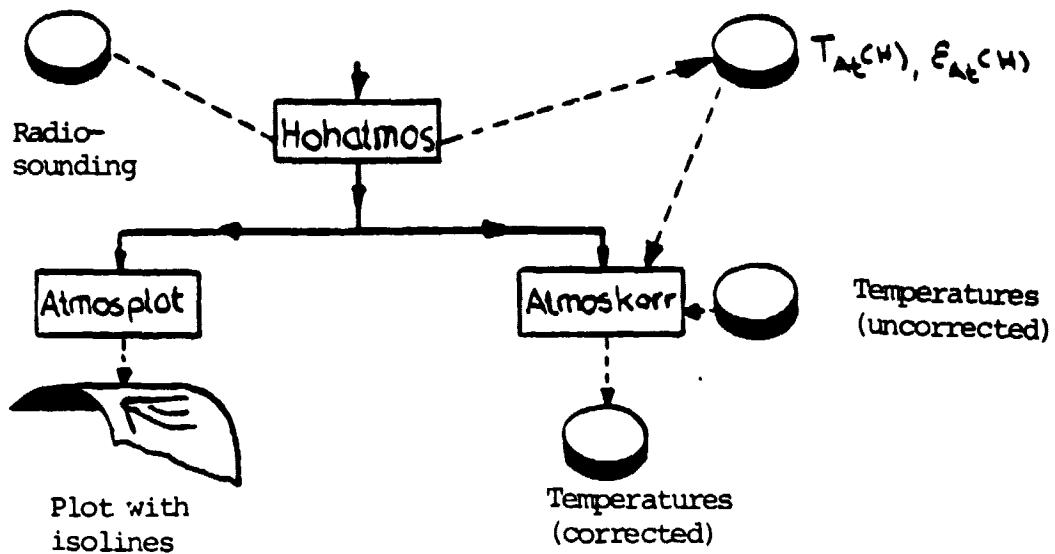
For a specific geographic area, map coordinates (center points of a grid of .25 km) and the respective image coordinates were listed and then data points were arranged in the appropriate order on a new data set (ZU 2. DATA).

In the case of the Lannion-data (without HOTINE OBLIQUE MERCATOR projection), the panoramic distortion of the radiometer as well as earth curvature had to be eliminated first, before the multiple linear regression could be applied.

#### 5.2. Atmospheric corrections

In the initial phase of our HCMM evaluation the RADTRANS-program provided by NASA contained several errors. Therefore, efforts have been made to work out our own correction program (HOHATMOS). The influence of water vapor was considered significant between terrain surface and the 300 mb-niveau of the atmosphere. 15 - 20 data triples (air temperature, water vapor content, air pressure) were chosen at selected points of the radio sounding.

Fig. 13: Computer-Programs for atmospheric correction  
(Explanations same as in fig. 12). Ref.: SCHWAB, 1981:77.



The influence of the atmosphere at different altitudes of the terrain was calculated using the formula

$$\Delta T (H, T_E) = (T_E - T_A (H)) \cdot \varepsilon_A (H) \cdot \cos \beta$$

Numeric integration of the radiation transfer equation (program HOHATMOS) provided values for the mean temperature and mean emissivity values for the atmosphere, starting at different altitudes (steps of 100 m).

$\Delta T$  : atmospheric correction

$H$  : height above sea level

$T_A$  : mean atmospheric temperature at  $H$

$\varepsilon$  : emissivity of the atmosphere

$\beta$  : viewing angle between satellite and terrain

$$T_{\text{sat}} = T_E - \Delta T$$

As an example, a diagram based on radio sounding of Payerne Sounding Station shows the influence of the atmosphere as a function of terrain altitude (fig. 14 b). The example makes it clear that significant errors in the order of up to several degrees have to be taken into consideration when analysing temperatures in the lowlands (Swiss Plateau). On the other hand, in high altitudes (above 3000 m) the temperature deviations can almost be ignored. Also at night errors are generally reduced due to the smaller surface temperature range.

Accuracy of topoclimatological analysis in hilly terrain greatly depends on how representative the radio sounding data is. Humidity variations in time and space very often can not be ignored (see report No 2: Fig.1). On the other hand, availability of suitable data for the low troposphere is very limited (sounding stations only in Stuttgart, Munich, Milan).

### 5.3. Comparision between radiometric corrected HCMM and ground truth data

For 3 HCMM scenes differences between atmospheric corrected satellite data and ground truth measurements were determined. The results are listed below:

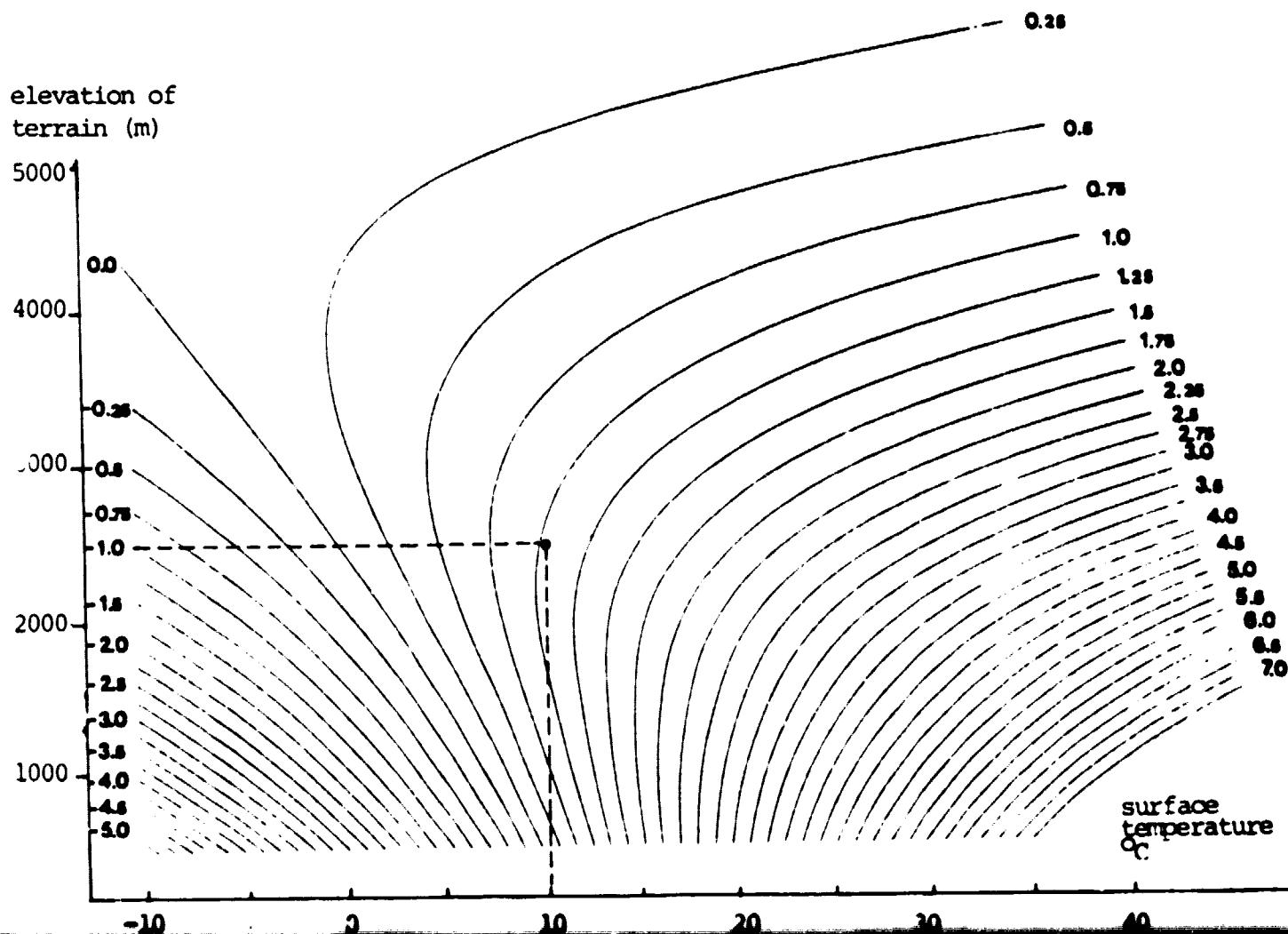
Tab.1: Comparison between radiometric corrected HCMM data and ground truth measurements.

Date Time Origin of tape	Test areas	Ground truth T (° C)	Surface temp. incl. atmosph. correction	Atmosph. corr. surf. temp. as measured by HCMM	"Error" of HCMM-radio- meter
31.8.1979 11.55 UT LANNION	Lake Murten Melting snow (Aletsch) Seeland (agricultural)	+ 21.5 0.0 + 32.5	+ 19.2 0.0 + 28.9	+ 13.5 - 4.5 + 20.8	- 5.7 - 4.5 - 7.8
16.5.1979 00.37 UT LANNION	Lake Murten Seeland (agricultural) Lake Brienz	+ 15.0 + 9.5 + 11.0	+ 13.8 + 9.2 + 10.4	+ 5.1 + 0.5 + 2.0	- 8.7 - 8.5 - 8.4
3.6.1978 01.49 UT NASA	Lake Brienz	+ 12.8	+ 12.2	+ 12.0	- 0.2

Fig. 14a: Radio Sounding of Payerne Station for 16.8.78,00 UT.  
Data set used to determine the correction diagram  
shown in fig. 14b.

pressure (mb)	air temperature °C	dew point difference °C
966	16.53	2.58
956	17.21	4.08
892	14.5	4.22
850	13.4	4.9
794	8.6	2.04
705	3.0	1.4
627	-2.7	2.86
581	-7.9	1.1
558	-10.0	1.8
536	-10.7	2.8
502	-12.7	9.1
480	-15.8	10.9
469	-18.6	5.2
439	-21.1	10.0
403	-24.0	10.5
388	-28.0	2.5
350	-32.7	5.8
318	-38.8	2.6
281	-45.5	4.9

Fig. 14b: Diagram to determine the atmospheric correction as a function of  
surface temperature and terrain elevation. Example: Surface temp.  
= 10 °C, terrain elev. = 2500 m → correction value  $\Delta T = 1.1^\circ\text{C}$ .  
Ref.: SCHWAB, 1981:82.



In the case of 3 June 1978 the result is within the temperature resolution range of the HCMM radiometer. In both other situations the remaining differences between atmospheric corrected HCMM data and the respective ground truth control measurements remain in the order of -6.0 to - 8.6 ° C. These results coincide remarkably well with those compiled by REINIGER (1981 : 6): 3.6.1978,  $\Delta T = + 1.4 ^\circ C$  (Lake Geneva); 31.8.1979,  $\Delta T = -6.7 ^\circ C$  (Lake Geneva). Up to now we have not obtained enough information, to give reasons for these significant errors. As a consequence, for most of our climatological interpretations we decided not to introduce atmospheric corrections.

## 6. TOPOCLIMATOLOGICAL RESULTS

The results related to topoclimatology are presented in the following three examples (6.1. - 6.3.). They all deal with surface temperatures, basically with the question of which factors predominantly determine their statial pattern.

### 6.1. Nighttime temperature distribution in the Swiss Alps

- A first approach using analog images and covering large areas is shown in fig. 9 (chapter 4): The predominant temperature pattern for Switzerland is, at night, clearly determined by the large scale topography (Jura, Swiss Plateau, Alps and alpine valleys) with a distinct temperature sequence: - cold valley floors and basins,
  - warm hill tops and valley slopes
  - cold mountain tops (above 2000 m s. l.)

Within these three discernible units an irregular pattern of local temperature deviations can be related to mesoscale relief, but mainly to surface coverage types (forest, agriculture). Different exposures are of minor importance.

- Differences between HCMM scenes taken under comparable meteorological conditions, are very small, when related to the relative temperature course (fig. 15 a).
- For the scene of 16.5.1979, 00.37 UT the correlation between terrain altitude and surface coverage type is given in table 2 (SCHWAB, 1981 : 110).

Table 2: Correlation between terrain elevation and surface temperature for different coverage types.

surface coverage type	90 % confidence interval of temperature gradient ( $^{\circ}$ C/100 m)	Number of values	Correlation coefficient
Forest (slopes)	0.47 - 0.63	68	- 0.798
Forest (plains)	0.51 - 0.77	28	- 0.845
Agricultural (slopes)	0.44 - 0.50	64	- 0.938
Agricultural (plains)	0.40 - 0.48	111	- 0.869

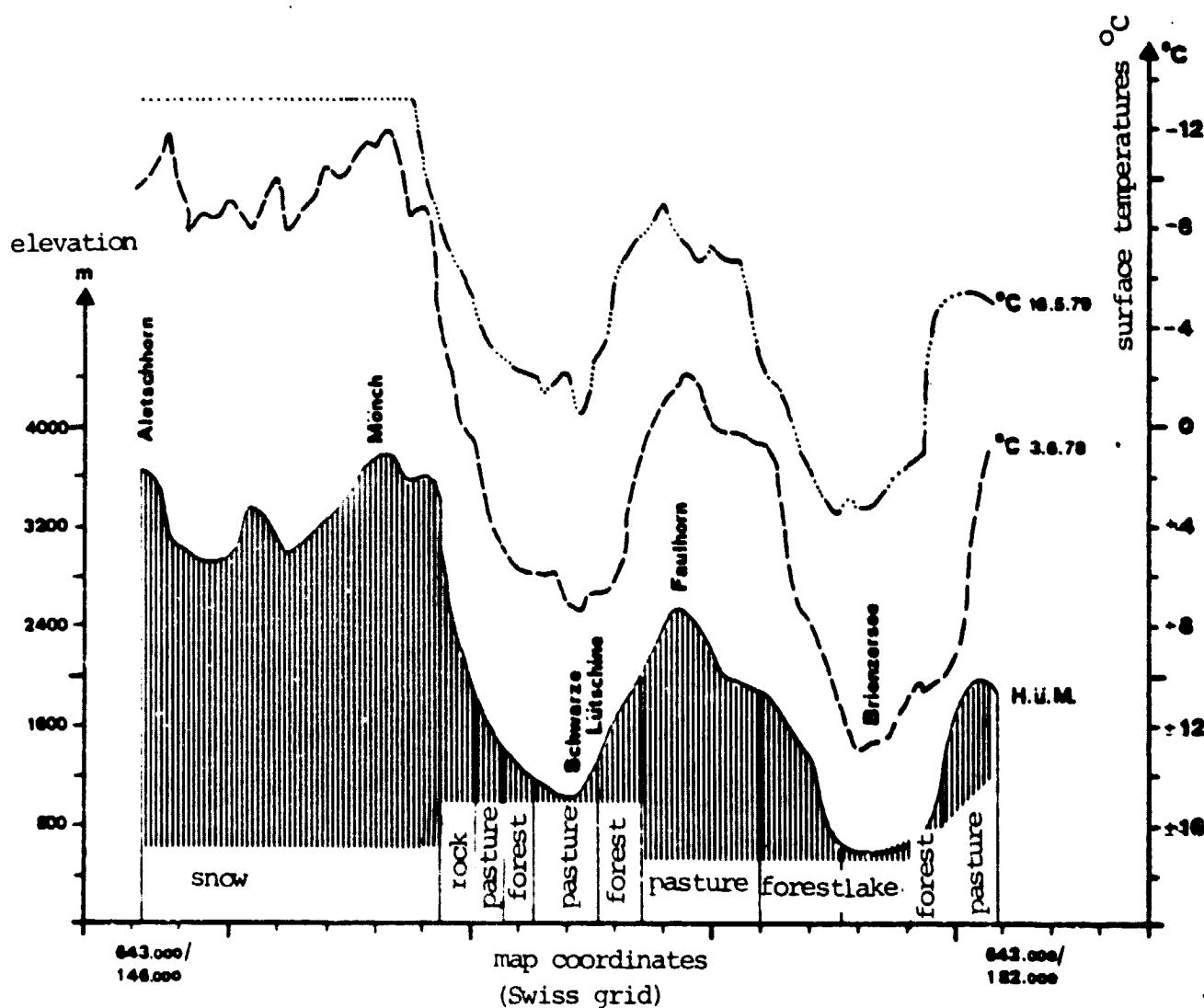
SCHWAB, 1981:110

It is evident that the valley floors show surface temperatures which are generally several degrees lower than those of the neighbouring hill slopes. The question is not yet answered, whether also air temperatures show a comparable distribution, or whether surface temperatures are highly correlated to the surface coverage type, as e. g. GOSSMANN (1980) demonstrated for the Upper Rhine valley. The result of our evaluation clearly shows that both, surface coverage type and topography, contribute to the change in surface temperature (WINIGER, 1980: Fig. 2).

Fig. 15: Comparison of 2 temperature profiles from Mt. Aletsch (Aletschhorn) to Lake Brienz in the Bernese Oberland. Both curves show the same relative course. Atmospheric corrections have not been taken into consideration.

HCMM nighttime scenes of 3.6.1978 and 16.5.1979.

Ref.: SCHWAB, 1981:109 (completed).



Air temperatures (minima measured in standard huts at 2 m above ground) from stations located at the valley bottom and the slopes on 18.11.1978, are drawn in fig. 16 (NEJEDLY, 1980 : 115). It is evident that there is, without an exception, a temperature difference ranging between 3 to 8 ° C. This example which is related to the Wallis (main valley in the Swiss Alps) could be transferred to other valleys and basins and is true for other comparable meteorological situations.

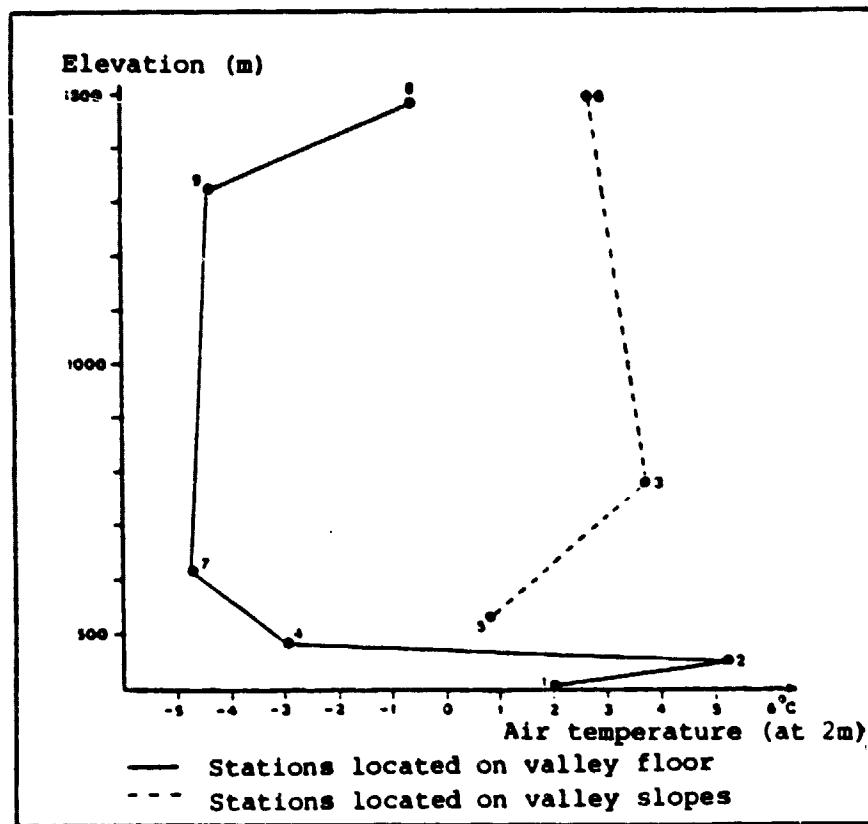


Fig. 16: Comparison between air temperatures of a profile along the valley floor and one climbing valley slopes.

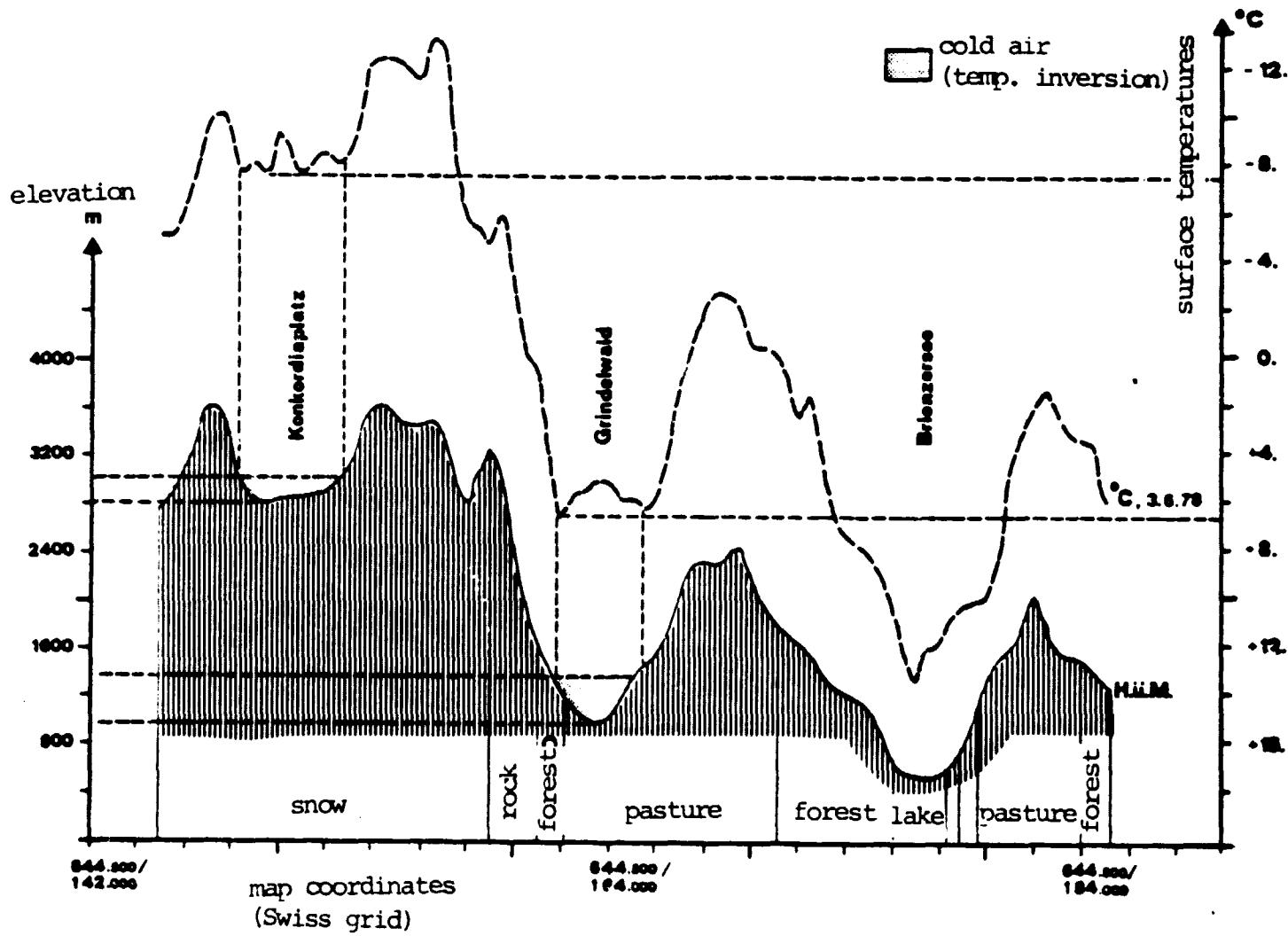
At night (16.11.1978) the cold air is clearly concentrated in the valley (inversion).

(NEJEDLY, 1980:105)

As one of the major conclusions we would like to point out that night HCMM-IR data allows delineation of reservoirs of stagnating cold air masses, as shown in fig. 17. The temperature transsect through the basin of Grindelwald contains two remarkable inversions: one on the extended Concordia

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Fig. 17: Surface temperature profile through the Bernese Oberland from the Aletsch Glacier (Konkordiaplatz) to Lake Brienz (North - South). The cold zones of the two basins Aletsch Glacier (Konkordiaplatz) and Grindelwald are clearly detectable, slightly modified by changes in surface coverage. Nighttime HCMM scene of 3.6.1978 (no atmospheric corrections). Ref.: SCHWAB, 1981:115 (modified).



HCMM: SURFACE TEMPERATURE / TERRAIN ELEVATION BERNES OBERLAND

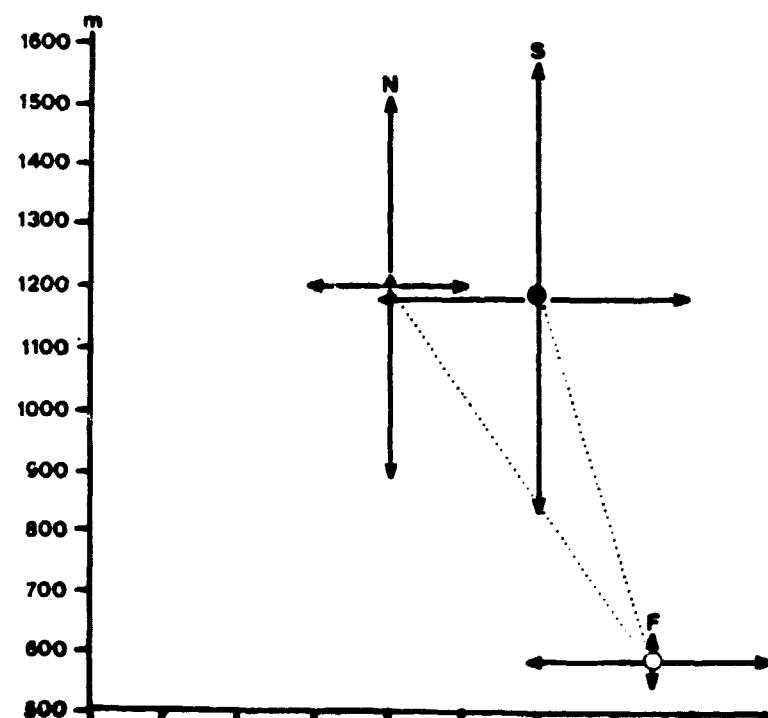
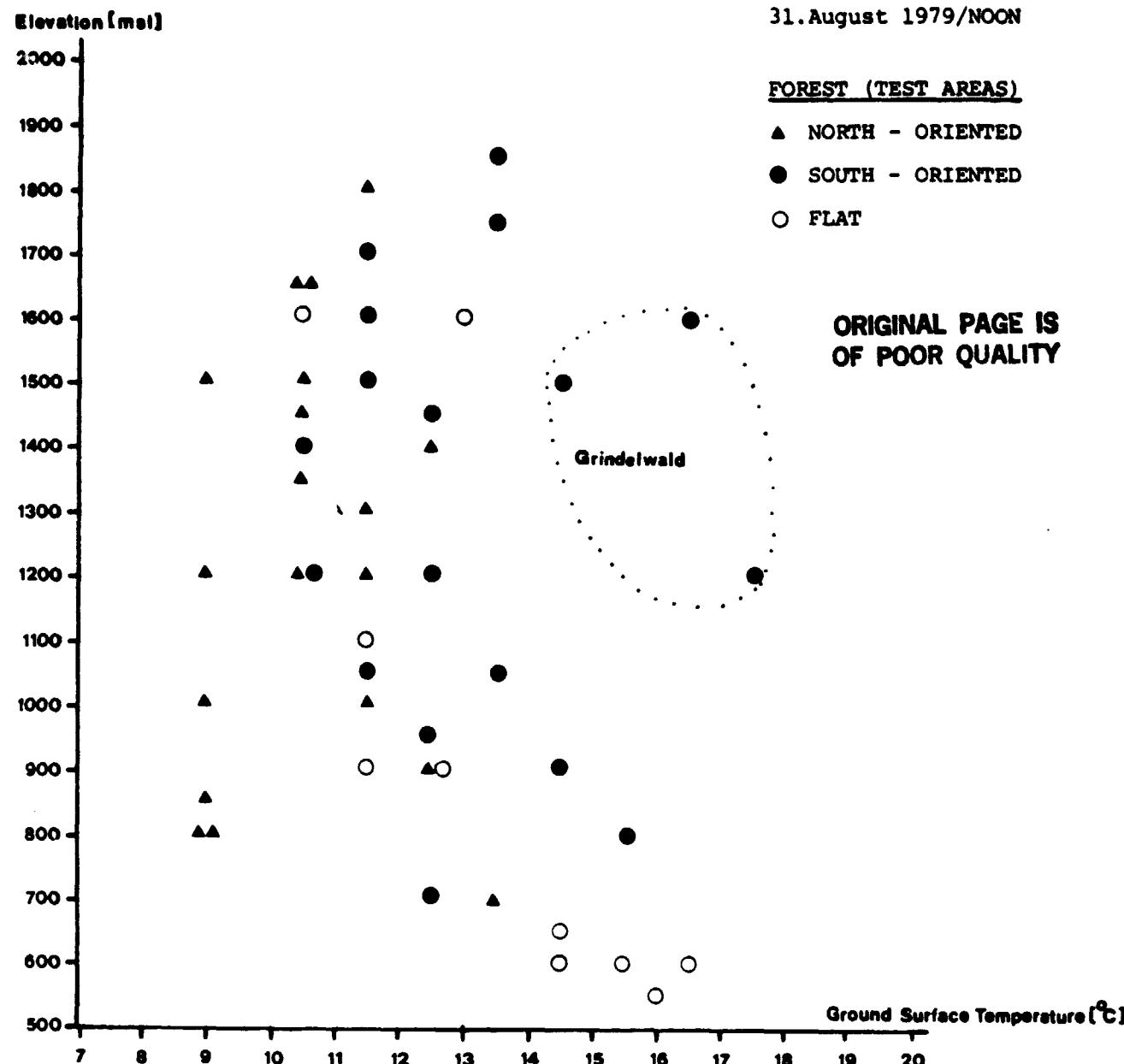


Fig. 18:  
Comparison of surface  
temperature of forested  
areas for different expo-  
sures and altitudes.

Upper figure: individual  
test samples.

Lower figure: standard  
deviations of temperature  
altitude for different  
exposures, using values  
of upper figure.

Plateau on the Aletsch Glacier, the other one in the almost circular basin of Grindelwald. Also weaker flows of cold air could be outlined under favorable conditions (GOSSMANN, 1980).

#### 6.2. Daytime temperature distribution in the Swiss Alps

A similar approach to that briefly outlined in 6.1. has been undertaken for daytime HCMM-IR scenes. In contradiction to the nocturnal temperature distribution, during daytime, especially at noon, altitude is a less distinctive factor. Main differences are due to terrain exposure and once more due to surface coverage types. Fig. 18 contains the results for forested areas of the Bernese Oberland (northern and southern slopes and flat areas).

#### 6.3. Urban heat islands

Topoclimatological evaluations clearly include investigations about urban heat islands. GOSSMANN (1981) gave examples for the Ruhrgebiet (FRG), CARLSON presented comparable studies for US agglomerations at the investigator meeting at GSFC (1980). A similar approach has been carried out for the agglomeration of Berne (250 000 inhabitants) and shown in fig. 19.

The average increase of surface temperature from the surrounding rural areas towards the urban center is approximatively  $+ 3^{\circ}\text{C}$  for a midsummer scene at noon (31 August 1979). Subsidiary thermal centers are located in the suburbs and other built up areas with a population above 1000 - 5000, or in industrial sites of a comparable size. The change in surface temperature clearly depends on the density of buildings within a certain area, or on the percentage of vegetation. For the city of Berne a correlation of  $r = -0.75$  to  $0.85$  exists between the percentage of vegetation cover (estimated from areal photographs) and the respective surface temperatures.

A comparision with the heat island (air temperatures) derived from measuring campaigns along profiles across the city of Berne shows a surprisingly detailed coincidence: the thermal pattern is the same, although the date and time of day differ between the HCMM-scene and the profile measurements (fig. 19, lower part). Within one year 24 ground based air temperature campaigns have been carried out, covering some 100 control points. Although absolute values and local thermal patterns changed depending on the meteorological situations, the principal "heat centers" were usually located at the same places (ABEGGLEN and ENGEL, 1982).

The evaluated examples showed that for medium to small scale heat island investigations HCMM provides data of adequate spatial and thermal resolution. This is of course even more true for larger extensive cities such as Milan (NEJEDLY, 1980, SCHWAB, 1981).

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Fig. 19a: Heat Island of the agglomeration of Berne (broken line) derived from HCMM scene 31.8.1979, 12.00 UT. Surface temperatures without atmospheric correction.



Fig. 19b: Heat island of the agglomeration of Berne (broken line) resulting from ground based measurements on 21.10.1980, 19.30 UT. Air temperature measured 2 m above ground, shown as differences to the value measured at Point A. The principal pattern is the same as in Fig. 19a.  
(ABEGGLEN, 1982).



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SURFACE TEMPERATURE DISTRIBUTION RELATIVE TO TOPOGRAPHY



COLD

(MOUNTAIN TOPS)



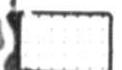
COLD

(VALLEY BOTTOMS)



WARM

(VALLEY SLOPES AND TOPS)



HAZE, FOG

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TEMPERATURE DISTRIBUTION RELATIVE TO TOPOGRAPHY

(MOUNTAIN TOPS)

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(VALLEY BOTTOMS)

(VALLEY SLOPES AND TOPS)

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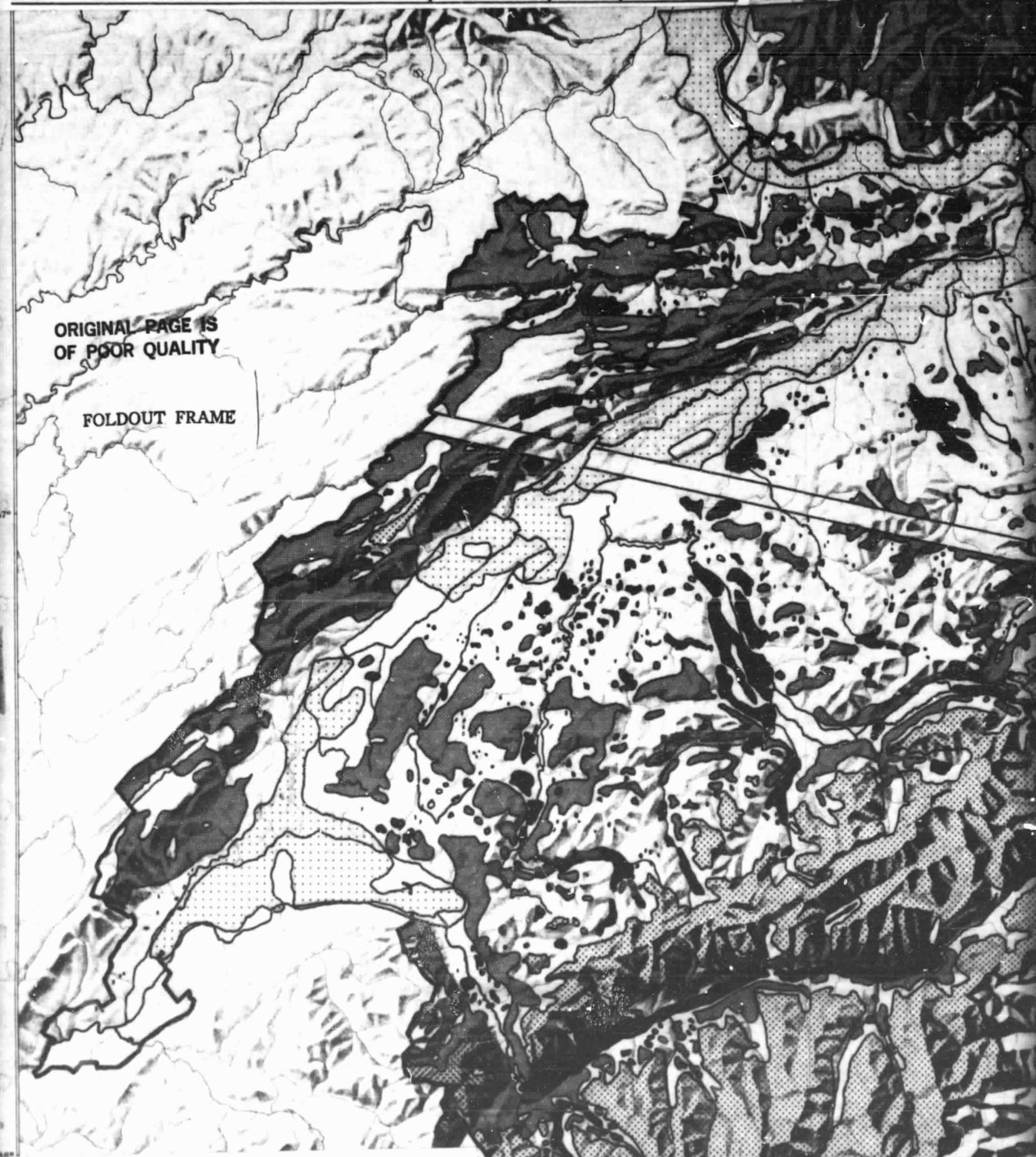
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# RELATIVE SURFACE TEMPERATURE DISTRIBUTION

DERIVED FROM HCMM—DATA, NOV. 16, 1978, 01.36UT



# DISTRIBUTION OF SWITZERLAND

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SURFACE TEMPERATURE DISTRIBUTION RELATIVE TO TOPOGRAPHY



COLD

(MOUNTAIN TOPS)



COLD

(VALLEY BOTTOMS)

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RETO TO TOPOGRAPHY

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## 7. SUMMARY OF RESULTS AND CONCLUSIONS

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We would like to summarize the main results of our investigation as follows:

### 7.1. Methodical aspects

- Analog image interpretation (based on transparencies, opto-electronic device) is a suitable approach for relative temperature evaluations in topoclimatology.
- Digital evaluation is possible within a location-accuracy of  $\pm 1$  pixel.
- Radiometric corrections depend highly on the atmospheric conditions and may vary within short horizontal distances (due to topography).
- Ground truth measurements are needed to get accurate data calibration. Melting snow fields (surface temperature = 0 ° C) proved to be excellent ground control areas. Water bodies should only be used as control areas when measurements are carried out along profiles (PRT-5 overflights).

### 7.2. Climatological aspects

- Surface temperature distributions very much depend on surface coverage types and on topography.
- At night the following thermal pattern is typical for mountainous areas: cold valley floors - warm hill slopes - cold mountain tops. This pattern is significantly modified by different surface coverage types (forest with highest temperatures). Air temperature inversion zones are detectable.
- During the day surface coverage type is equally important. It is modified by exposure and less by altitude.
- Urban heat islands can be analysed on a medium and small scale. Temperature patterns are determined by the percentage of vegetation within built up areas.

7.3. Recommendations

- For medium scale topoclimatic surveys no higher spatial resolution is required. Higher resolution would ease location of ground controls, but would increase data handling problems.
- Thermal resolution is equally sufficient for topoclimatic studies but lower and upper limits should be extended for studies in very cold areas (high altitudes).
- We would highly recommend introducing, on future meteorological satellites (TIROS-N type), multichannel thermal radiometers with comparable spatial resolution such as HCMR.

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